Development and Application of a Multi-scale Process-Based Framework for the Hydromorphological Assessment of European Rivers

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Abstract

Many current river assessment methods emphasise the river 'reach' scale (a fixed length of river of the order of a few hundred meters) and provide a wealth of useful information that characterises the river corridor at the time of survey. However, they also have several limitations when they are used for understanding physical processes and causes of river alteration. A multi-scale, process-based framework is needed, which incorporates reach scale information into a larger spatial and temporal assessment of the controls on reach dynamics, and a process-based interpretation of the contemporary status of reaches, their historical dynamics and their likely future trajectories of adjustment. This paper reports on the early development and application of a multi-scale framework that is applicable to European rivers and is aimed at improving understanding of hydromorphological and ecological processes and their interactions. This ongoing research is part of the EU-funded project REFORM (REstoring rivers FOR effective catchment Management) which has the overall aim to provide a framework for improving the success of hydromorphological restoration measures in a cost-effective manner, targeting the ecological status or potential of rivers.

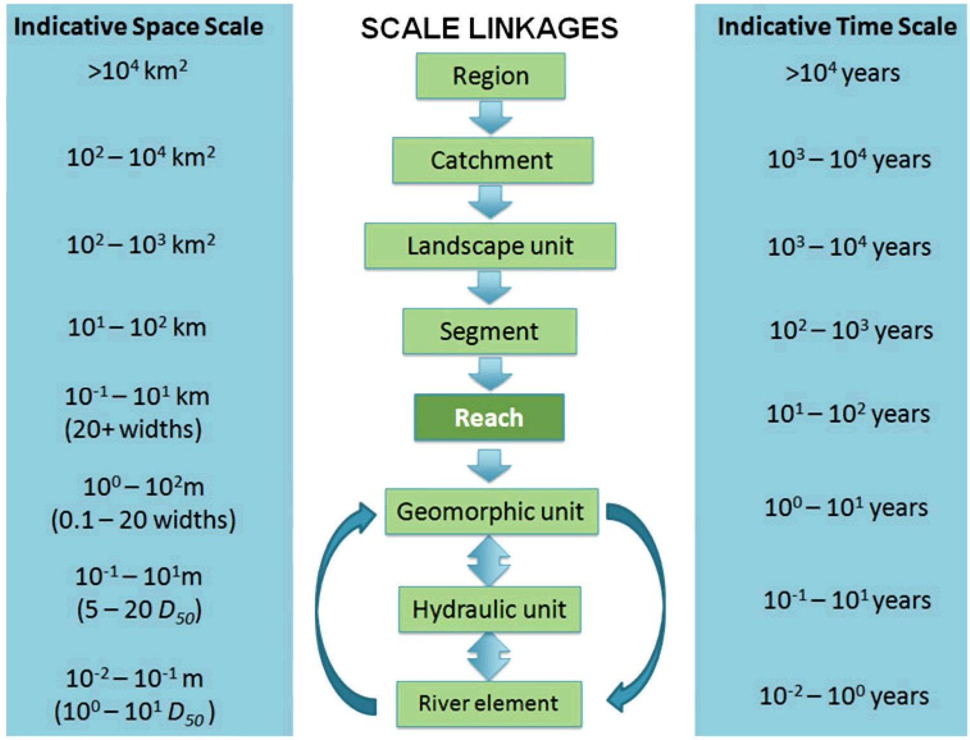
Keywords

River condition • Spatial hierarchical framework • Temporal change

Introduction

The EU FP7 project REFORM (REstoring rivers FOR effective catchment Management) has the overall aim of improving the effectiveness of hydromorphological restoration measures in order to target the ecological status or potential of rivers. Many current river assessment methods employed by EU member states emphasise the river 'reach' scale: a fixed length of river of the order of a few hundred meters (Rinaldi et al. 2013a). While such assessments generate much useful information, they may not be sufficient to fully contextualise current river condition or support proposals for river restoration. Although restoration is ultimately applied at a reach scale, the condition and stability of any river reach is dependent upon larger-scale hydromorphological processes and their changes through time. Furthermore, organisms found within a reach respond to more than the current local hydromorphological conditions. During their life cycle, organisms are affected by dynamic physical processes, by the assemblage of morphologies (habitats) within and beyond any particular reach; and by interaction between processes and forms at multiple scales in relation to dispersal, feeding, reproduction and

Fig. Hierarchy of spatial scales for a European framework for hydromorphology, including indicative spatial dimensions of units at each scale and typical timescales over which the units may show significant adjustment



survival, particularly during extreme events. For these multiple reasons, it is important to develop reach-scale understanding and restoration design within the context of processes and forms across larger spatial scales, and in a dynamic temporal framework.

A Multi-scale Framework

Many hierarchical approaches have been proposed to support better understanding of the functioning of river catchments, corridors and networks (e.g. Frissell et al. (1986); Montgomery and Buffington (1998); Habersack (2000); Kondolf et al. (2003); González del Tánago and García de Jalón (2004); Brierley and Fryirs (2005); Thorp et al. (2006); Beechie et al. (2010); Rinaldi et al. (2013b); Wang et al. (2012)). Each of these approaches was developed with particular applications in mind. In the present research, we aim to develop a hierarchical framework that makes optimum use of available data and is sufficiently flexible to be suitable for application across Europe. This framework reflects the fact that the hydromorphological character of a river reach is driven by (i) regional characteristics (climate and geology), (ii) catchment characteristics that translate regional climate properties into flows of water and sediment through the river network, (iii) the valley setting, which dictates the topographic slope and lateral confinement of river reaches, and (iv) local reach-scale factors, such as the calibre and structure of river margin and floodplain sediments, and the assemblage of aquatic, wetland and terrestrial vegetation, which moderate the local hydromorphological responses to the river's flow and sediment transport regime.

The hierarchical framework provides the context for (i) delineating spatial units within a catchment, (ii) characterising those units in relation to their current and past condition, and then (iii) deriving key indicators from the characterization that can provide understanding of why a particular reach displays a particular condition, whether that condition is relatively stable or is changing, and thus what its future properties may be.

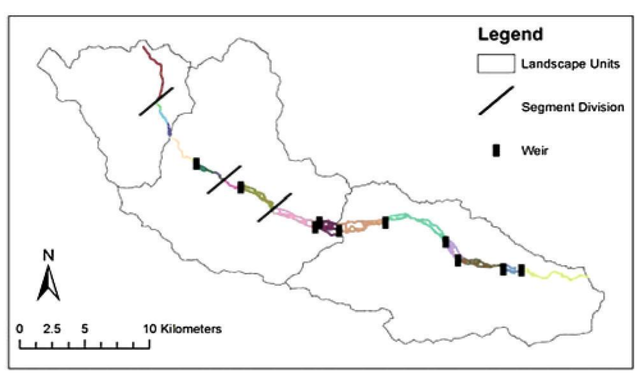


Fig. Delineation of the River Frome

Table Example indicators of condition according to spatial scale

KEY PROCESS	ASSESSED CRITERIA	CONDITION INDICATOR	ALTERATION PRESSURES
		CATCHMENT	
Water yield Sediment yield	Catchment Area Runoff ratio Geology Land cover	Catchment area Runoff ratio Geology: % WDF types Land cover: (% types significant for runoff ratio)	Water transfers, Large dams Land cover change
		LANDSCAPE UNIT	
Water yield	Rapid runoff production Delayed runoff production	Bedrock permeability Exposed aquifers Land cover (classes influencing rapid / delayed run-off	Water resource development Changes in snow and glacier mass balance and land cover
Sediment production	Fine/coarse-sediment	Soil erosion rates % unstable land surface.	Intensification of agriculture,
		SEGMENT	
River flows Sediment regime River dynamics Wood production	Flow regime Fine and coarse sediment supply Valley controls Riparian corridor features Potential wood delivery	Hydrological regime, average and extreme flows Fine and coarse sediment delivered to channel Average sediment budget Average valley gradient Valley confinement Riparian corridor width, continuity Active channel edge bordered by living/dead trees	Flow regulation, groundwater abstraction Changes in river margin land cover and management. Sediment mining Embanking Vegetation alteration Wood removal
		REACH	
Flooding Channel morphology	Flood area Flow energy Sediment calibre Channel form and position	% floodable floodplain Specific stream power Bed / bank sediment size Channel type, gradient, size, geomorphic features	Flow regulation and change in sediment delivery
Channel adjustment	Lateral migration Channel width and depth change	Bank erosion / migration, Changes in width, depth, bed sediment, geomorphic units, riparian corridor size.	Flow regulation, channelization
	Constraints on channel adjustment	Bed, bank reinforcement, width of erodible corridor, channel structures.	Embanking Reinforcement
Vegetation succession	Vegetation dynamics	Emergent aquatic vegetation and riparian vegetation structure	Riparian groundwater change, aquatic and riparian vegetation and wood removal
Wood supply	Wood quantity	Wood amount/distribution	

Delineation, Characterisation and Indicators

Catchments are delineated into landscape units, segments and reaches according to a set of rules, with smaller spatial units nested within larger spatial units so that their boundaries correspond. This nesting allows the framework to be used for overall catchment assessment and management purposes; or to focus on one or a few reaches or segments that are under investigation for restoration or other management, allowing downscaling or upscaling the reciprocal interactions between processes and patterns. For example, the delineation of the main River Frome, England
splits the river into 3 landscape units based on elevation,

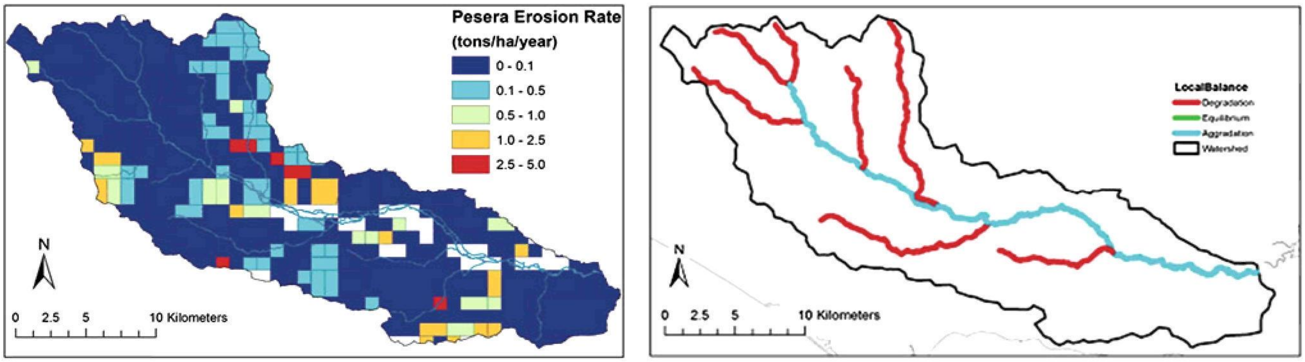


Fig. Soil erosion rates (*left*) can be used to estimate sediment delivery to the channel network and the fate of the sediment can then be modelled (*right*, *red* = degradation, blue = aggradation)

geology and land cover, 6 segments based on major changes in valley gradient, major river/stream confluences and valley confinement, and 17 reaches based on changes in river planform and the presence of major weirs.

Once the spatial units are delineated, the current condition and relevant historical changes of the units are characterised to develop an integrated understanding of how the catchment is functioning and the degree to which it is in a dynamically stable condition or is undergoing change. A series of indicators are then extracted from the information assembled during characterisation. Table lists some examples of indicators representative of the different spatial scales. Each of these can be explored in terms of their current or past state, or their state under particular conditions or pressures, allowing assessments of current and past condition of spatial units and linkages between them.

For example an assessment of land cover change in different landscape units and the current sediment budget status of segments can be used to interpret (i) the current sediment status of reaches of different type within each segment; (ii) the degree to which reaches may be undergoing changes in response to excess or shortage of sediment; and also (iii) reach sensitivity to different management inter-ventions at landscape unit to reach scales . The sediment budget is useful for explaining observed fine sediment infiltration of river gravels and accumulation on the river bed. At the reach scale, observed geomorphic units illustrate interactions between aquatic vegetation and fine sediment and explain river planform and depth dynamics in response to delivered fine sediment. From this, projections can be made of likely river change following changes in land cover/management, flow regime, aquatic/riparian vegetation management, and weir removal.

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